CRYOGENIC 90 GHz RECEIVER FOR AIRBORNE RADIOMETRY

B.Vowinkel, J.K.Peltonen+, W.Reinert

Radioastronomisches Institut der
Universität Bonn, Auf dem Hügel 71
D-5300 Bonn 1, F.R.Germany

+ on leave from Helsinki University of Technology

K.Grüner, B.Aumiller

DFVLR, Institut für HF-Technik
D-8031 Oberpfaffenhofen
F.R.Germany

ABSTRACT

A cryogenic 90 GHz receiver has been developed that has a noise figure of 2.36 dB (DSB) with an instantaneous bandwidth of 1.2 GHz. The cooled front-end consists of a Schottky-barrier mixer with built-in GaAs FET IF amplifier. The system is small in size and has a relatively low weight, so that it can be used for airborne radiometry even in small aircrafts.

INTRODUCTION

Airborne millimeter-wave imaging systems are of great practical interest for the remote sensing of the environment. Especially the frequency region around 90 GHz is very useful, because on the one hand a high angular resolution can be achieved with small antennas and on the other hand contrast losses due to weather conditions are still small. Airborne systems to date have yielded excellent results[1,2,3] but have also shown that a further reduction in the receiver noise temperature is necessary.

The improvements in solid state millimeter-wave devices and GaAs FETs in the last years and the availability of small size closed cycle refrigerators have made it possible to develope a cryogenic radiometer with a state-of-the-art temperature resolution and relatively low weight.

BASIC CONCEPT

The imaging system consists of an oscillating parabolic mirror, a cryogenic radiometer and a digital data processor (see Fig.1). The data are recorded on magnetic tape for further analysis on the ground and also displayed on a screen for quick look evaluation. The minor axis diameter of the mirror is 200 mm, giving an angular resolution of about 1^{o}.

The radiometer is a total power system, consisting of a cryogenic GaAs Schottky-barrier mixer with built-in GaAs FET IF amplifier and an uncooled IF postamplifier with high gain. The mixer is driven by a Gunn oscillator. Fig.2 shows a block diagram of the front-end. The cooled components are located in a vacuum chamber in order to prevent convection and condensation of the air. In front of the horn antenna is a 50 µm thick Mylar window, that has negligible insertion losses at mm-wavelengths.

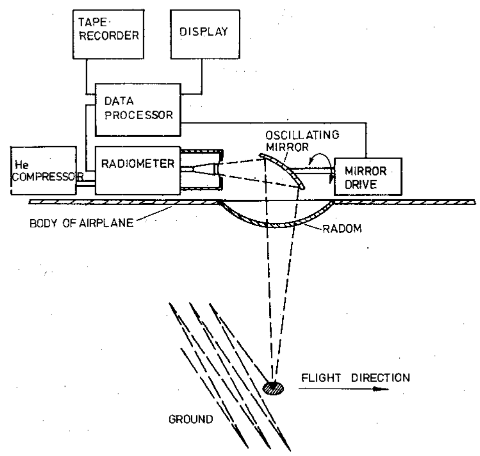

Fig.1. Sketch of the principal configuration

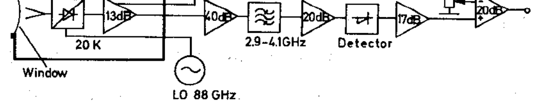

Fig.2. Block diagram of the radiometer

The cooling to about 20 K is provided by a closed cycle refrigerator that uses helium as coolant. The two-stage expander module is part of the front-end whereas the compressor unit is seperate. Both parts are connected via two flexible helium pipes. The power consumption of the compressor is 1.1 kW and the weight is 39 kg. The weight of the radiometer front-end is 13 kg (including expander module).

GUNN OSCILLATOR

The frequency determining element of the oscillator is a radial disk with a diameter of about $\lambda/2$ (see Fig.3), located in a full height WR-12 waveguide[4]. The adjustment of the oscillation frequency was achieved by a step by step reduction of the disk diameter. In order to prevent mechanical sensitivity, no tuning elements are used. Also the backshort is fixed at a distance of about $\lambda_g/4$ to the center of the resonator. The optimum distance for each diode that has been tested, was found experimentally in a test oscillator with adjustable backshort.

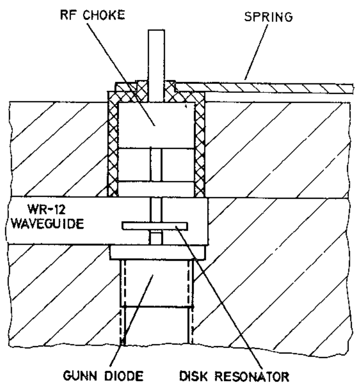

Fig.3. Cross sectional view of Gunn oscillator

The maximum output power that has been achieved was 30 mW at 88 GHz using the 2nd harmonic oscillation of a commercial 44 GHz Gunn diode. For the radiometer an oscillator of lower output power was used, because the power requirement for the mixer was only about 1 mW.

MIXER

The mixer is a broad-band version of the design presented at the 9th EMC[5]. The LO is coupled via a TE_{111}-mode cavity filter into the signal waveguide, which is an electroformed transition to a reduced height (1/3) cross section. The GaAs Schottky-barrier diode was fabricated in our laboratories by means of electron beam lithography,using commercially available substrate material with an epilayer thickness of 0.15 μm and a doping concentration of 2 10^{16} cm^{-3}. The diameter of the Schottky-contacts is 2.5 μm, giving a series resistance of 9 Ohm and an η-factor of 1.09. The diode is soldered to a coaxial low-pass filter, that rejects the RF. A mixture of Araldite and quartzmeal was used to fix the choke. The measured conversion loss of the mixer is 5.8 dB and the SSB noise figure is 5.7 dB (790 K) at room temperature and 2.0 dB (170 K) at 20 K (without IF contribution, but including losses of: horn antenna, circular-rectangular transition, LO coupling circuit and IF matching circuit).

The 3-4 GHz band was chosen for the IF. Optimum IF impedance levels ranging from 80 to 120 Ohm were estimated for the Schottky-diode in a broadband mixer. After the RF choke, the transformed IF impedance was matched to a 50 Ohm line with short sections of successively high (air between conductor and ground plane) and low impedance transmission lines to minimize the IF losses within the bandwidth of 1 GHz. The high impedance microstrip line also reduces stresses between the diode mount and the matching circuit at cryogenic temperatures. The dielectric substrate material used for the low and medium impedance sections is Teflon/glass cloth laminate.

CRYOGENIC GaAs FET AMPLIFIER

A single-stage, small size FET amplifier for the 3-4 GHz IF band was developed to enable cooling of the preamplifier.A nominal transducer power gain of 13-14 dB was chosen to reduce the postamplifier contribution for the total IF noise temperature to about 10 K and to maintain amplifier stability during the cooling experiments. The transistors NE 24483, NE 38883 and MGF 1402 were used in the amplifiers. Although the 0.5 μm gate length transistor gave the lowest noise figure at room temperature (1.36 dB), best results at cryogenic temperatures were achieved with 1 μm devices. The results are listed in Table I.

The input match for optimum noise figure was realized using double section matching network consisting of short (less than 0.1 λ) high and low impedance transmission lines. A microstrip line in air utilizing the gate strip of the packaged transistor was used to raise the impedance level (to 190 Ohm) of the high impedance section resulting in a relatively broadband noise match. The measured loss of the input circuit with DC block was on the order of 0.2 dB.

A new source grounding technique was tested, using two small metal clamps screwed on the amplifier housing instead of soldering the source-lead to the microstrip ground plane. When the clamps are placed close to the transistor, good electrical grounding is ensured. On the other hand, the source inductive feedback can also be tested at these frequencies by moving the grounding clamps somewhat apart from the transistor. The effect of the feedback is to reduce the gain (to smooth a high peak at center frequency), broaden the bandwidth and improve the input VSWR of the amplifier.

The FET amplifier was integrated with the mixer mount in a common housing (see Fig.4). A 50 Ohm test port was added to facilitate seperate testing of the mixer and amplifier. The length of the 50 Ohm line was selected to compensate the residual mismatches between the IF port and the transistor at the band edges. Thus a cryogenic isolator was not absolutely necessary between the two circuits.

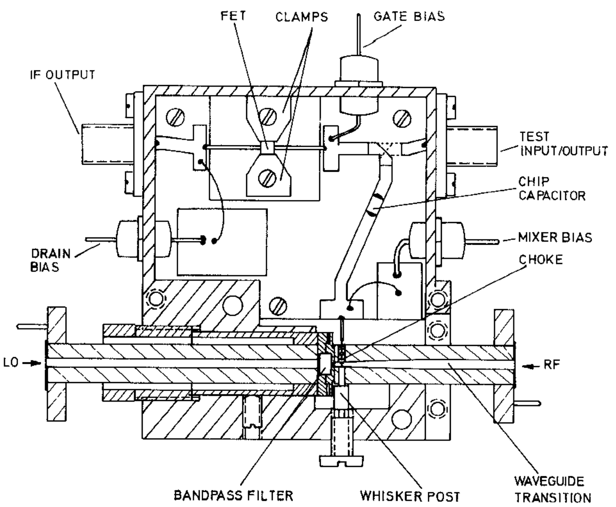

Fig.4. Cross sectional view of mixer/IF amplifier

PERFORMANCE OF THE RADIOMETER

The performance of a radiometer that is part of an imaging system can be expressed by the data rate (number of values per second) which is available for a temperature resolution of 1 K. Knowing the instantaneous bandwidth and the noise temperature of the radiometer, the data rate can be calculated:

$$N_{\Delta T=1K} = \frac{B}{\alpha^2 \, (T_A + T_{Rec})^2}$$

where B is the effective instantaneous bandwidth (Hz)

T_{Rec} is the receiver noise temperature (K)

T_A is the antenna noise temperature (K)

α is a constant depending on the type of receiver (e g Dicke system) α is ≥ 1

In airborne radiometry the antenna noise temperature T_A varies between about 290 K for forests and about 180 K for water surfaces. For metal surfaces (vehicles) antenna temperatures below 100 K are possible. For the calculation of the medium available data rate a value of T_A=250 K may be assumed. Table I shows the results for the presented radiometer obtained by hot-cold measurement method. The accuracy for the given noise temperatures is better than $\pm$ 10 K.

TABLE I

IF (GHz)	T_{Rec} (DSB)	T_{IF}^{+}	$N_{\Delta T=1}, \alpha=1$
room temperature (293 K)			
3.3 - 3.9	670 K (5.2dB)	140 K (1.7dB)	709 sec^{-1}
2.9 - 4.1	710 K (5.4dB)	160 K (1.9dB)	1302 sec^{-1}
cooled (20 K)			
3.3 - 3.9	190 K (2.19dB)	45 K (0.63dB)	3099 sec^{-1}
2.9 - 4.1	210 K (2.36dB)	55 K (0.75dB)	5671 sec^{-1}
Test system with cryogenic parametric amplifier			
3.7 - 4.2	113 K (1.43dB)	15 K (0.22dB)	3795 sec^{-1}

+) not including postamplifier contribution

For test measurements the mixer has been mounted in a receiver system with a cryogenic parametric IF amplifier. The result in this configuration was 113 K (DSB) (226 K SSB) for the total receiver noise temperature, which is considered one of the best values that have been reached up to now in this frequency region. For the final version the broad-band system with FET amplifier was chosen, to attain the highest available data rate (see Table I). The stability of this system is:

short term $<$ 0.005 dB/min

long term $<$ 0.02 dB/hour

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